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COMPETITION OR COOPERATION: A SIMULATION OF THE PRICE STRATEGY OF PORTS

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Abstract
Ports act as the nodes connecting water transport with land transport and play pivotal roles in logistics networks. The rapid rise in international freight volume has led to a faster growth in the throughputs of many ports. With the development of containerization, services provided by different ports could be substitutable with each other, especially those in the same region which are more competitive for substitutability. However, the question must be asked: is competition unchangeable? Moreover, is competition strategy always the best solution for ports? The purpose of this article is to analyse the issue of which strategy is better for ports: competition or cooperation. Using a modified Hotelling model, multiple competitors are analysed applying a competition strategy and simulations are developed of three ports with competitive and cooperative targets respectively. Research results reveal that, with the same service levels, location is a critical factor for competitive ports and, with a view to capturing greater market share, ports are motivated to form alliances.
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Key Words: Port, Competition, Cooperation, Hotelling Model

1. INTRODUCTION

Freight volumes have grown with the extensive development of international trade and the inevitable geographical dispersion of production. As a necessary transport mode, maritime shipping has had a strong and profound impact on the global logistics and supply chain network over recent decades. Ports act as the nodes connecting water transport and land transport together and play a pivotal role in logistics networks. The rapid rise in freight volume has led to a faster growth in the throughputs of many ports. With the development of containerization, services provided by different ports could be substitutable with each other. The rapid development of international container and intermodal transportation has drastically changed the market structure from one of monopoly to one where fierce competition is rife in many parts of the world. Many container ports no longer enjoy the freedom yielded by a monopoly over the handling of cargoes from their hinterland. Instead, they have to compete for cargo with their neighbouring ports [1]. Ports, especially those in the same region, became more substitutable, which has intensified competition between them for greater market share. The issue of port competition has been discussed from different perspectives and using various methods for years. Most academic studies indicated that competition has helped keep prices down and increase the efficiency and service quality of ports. However, is competition unchangeable? And is competition strategy always the best solution for ports? Looking at the port sector globally, there are successful cases of cooperation between ports, such as the New York/New Jersey, Los Angeles/Long Beach, Copenhagen/Malmo and Ningbo/Zhoushan combined ports. With this in mind, which then is better: competition or cooperation? This issue has been and will continue to be a central topic in academic literature.

The purpose of this article is to analyse which strategy is better for ports. Despite the fact that the competition issue has been discussed by numerous scholars, research on competition and cooperation taking place between multiple ports (i.e. more than two ports) has been lacking.

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If a country has a lengthy coastline, there are always multiple ports located along it which supply its economic hinterland. For example, China's mainland coastline is 14,500 kilometres long with five port groups and more than 150 sea ports. In order to capture freight source, huge capital has been invested to construct facilities and improve port service levels. Pricing has been one of the most commonly used strategies by competitive ports.

The paper is structured as follows. To begin with, we provide a brief background on the themes outlined in Section 1. Relevant research involving a game theory model applied to port competition is presented in Section 2. Section 3 is dedicated to the modelling of multi-competitors based on the Hotelling model. Section 4 then demonstrates the simulation of three ports under competition and cooperation conditions respectively. Lastly, Section 5 presents some conclusions plus some ideas for further work.

2. LITERATURE REVIEW

Previous studies into port competition have taken many qualitative and quantitative approaches, such as integer liner programming, dynamic programming, analytical hierarchy process, logit model, structural equation model, cointegration test and error correction model, transport cost model, transport demand model, and oligopolistic model [2]. Recently, a game theory approach has been used to study the port competition issue, which engendered interest from academics.

Throughout the history of research into game theory, many works focus on the application of non-cooperative game theory, where the solution concept is the Nash equilibrium. This game approach involves two or more players where each player is assumed to know the equilibrium strategies of the other players, and no player has anything to gain by changing only their own strategy [3]. This theory also attracted the attention of researchers from the port sector, such as Zhu, Reynaerts, Van Reeven, Saeed, Zhuang and Yip. Zhu et al. construct a super network of exporters and discuss the behaviour of shippers based on the theory of customer choice. The Hotelling model was used to express the choice of port, and the proof of the existence of a solution considering the Nash equilibrium condition was given. In particular, a dashed line was used to describe the process conducted by ports [4]. Reynaerts models container-handling competition in ports as Bertrand competition, arguing that competition in the terminal-handling business is based on prices and not quantities [5]. Van Reeven uses a symmetrical, spatial differentiation model with Cournot outcomes in order to analyse inter- and intra-port competition under two different governance schemes: landlord and service ports. The author examines the potential profits and prices under these two different settings. The paper shows that the landlord port model without intra-port competition is a Nash equilibrium and the dominant port model. It yields the highest profits and the highest prices for the industry. Even with the introduction of intra-port competition, it still gives higher profits and prices than the service port model [6]. Saeed et al. examine competition between ports by focusing on concession contract systems between PAs and TOs in three ports of Pakistan with the Bertrand model, where each terminal determines the charge for container handling and fees according to the signed contract [7, 8]. Zhuang et al. use a Stackelberg game and a simultaneous game to model port competition, where ports provide differentiated services in the sectors of containerized cargo and dry-bulk cargo [9]. Yip proposes a game model with which the effects of competition for sea port terminal awards can be studied. The modelling results mainly suggest that when a port authority has significant market power, it prefers to introduce inter- and intra-port competition, rather than allowing one operator to monopolize all terminals [10].

The Hotelling model is a game model on spatial competition. In a competitive environment, specialization of products and services is more likely than when competitors operate in a different environment. This argument can be related to the work of Hotelling (1929) who argues that competition between services provided at different locations is by nature oligopolistic because of the importance of transport costs [11]. The Hotelling model has been popular in different fields as a method to analyse the competition issue after Hotelling first put forward this model in 1929. Kaselimi and Ishii would subsequently make significant attempts over the years to apply the Hotelling model to port competition. Kaselimi et al. introduce a horizontal product differentiation model to analyse competition between container terminals using a game-theoretic approach. Their paper focuses on a landlord port management system with long-term concessions agreements shaping the formal relationships between the Port Authority and the private Terminal Operators. Starting from the linear city model of Hotelling, the authors develop a framework for Cournot competition between multi-user terminals. By comparing the results of different cases, the paper demonstrates how the shift toward a fully dedicated terminal impacts intra-port and inter-port competition between the remaining multi-user terminals [2]. Later, Ishii et al. examine the effect of inter-port competition between two ports. The authors construct a non-cooperative game-theoretic model where each port selects port charges strategically in relation to the timing of port capacity investment, derive the Nash equilibrium and obtain some propositions from the equilibrium, then apply the propositions to the case of inter-port competition between the ports of Busan and Kobe [12].

In summation, these researchers did not discuss the cooperation issue between multiple ports. In this paper, we aim to study the pricing strategy used by multiple competitors based on the Hotelling model under two different scenario settings. In the next section, we will introduce our basic model.

3. BASIC MODELING CONSIDERATION

In this section, we mainly discuss the optimal prices of multiple ports serving the same hinterland. The basic model is described first, then the ports' demand functions and profit functions are yielded, and lastly the equilibrium price matrix is solved.

The scope of this model is limited to exports to the port; therefore, the focus customers are the exporters (e.g. shipper, consignor or freight forwarder). Though they are on behalf of the different parties to the shipments, for instance the cargo owner, freight forwarder employed by the owner and so on, in our paper, these parties refer to the exporters.

Since each port serves its hinterland by acting as a door for imports and exports, we revise the traditional Hotelling model to accommodate the actual geographic situation. Unlike the original Hotelling model, we show that, with the location pattern for ports distributing along the line [0,1] (similar to the coastal line), consumers are distributed uniformly in the area covered by [0,0], [0,1], [1,0], [1,1], which is deemed as the hinterland for these ports. The Hotelling model proceeds with two stages, competitors choose locations in the first stage and set prices in the second stage. However, as the locations of the ports are fixed, we are only looking for the perfect Nash equilibrium of price.

Suppose there are n competitive ports located at the unit interval [0,1]. And port i ($i = 1, 2, \dots i, \dots, n$) is at $(a_i, 0)$, here $0 \le a_1 \le a_2 \le a_i \le \dots \le a_n \le 1$ (this constraint is identical to the fact), which means the locations of these ports are not coincidental. Consumers are equally distributed over the area, and $\omega(x_{i,i+1}, y_{i,i+1})$ is the location of the customer representing a two-dimensional point. The customer is endowed with utility $u_\omega(a_i, p_i) = k + \theta S_i - t(a_i - \omega)^2 - p_i$. $k > 0$ is the reservation price of the consumer. $S_i > 0$ represents the service level of port i, and $\theta > 0$ represents the coefficient of service level. t is the land freight rate from the consignor to the port. The term $t(a_i - \omega)^2$ can be interpreted as the quadratic transport cost. p_i represents the service price per unit charged by ports, including handling charge, towage, pilotage and port charge, and so on. Only if $u_\omega > 0$ do the consumers buy the port service. Fig. 1 demonstrates the locations of ports and customers.

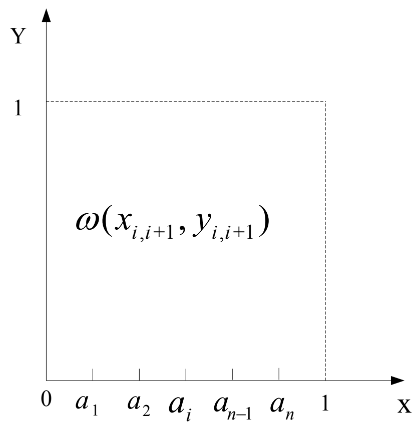

Figure 1: Locations of ports and customers in the same hinterland.

In the port market, price strategy becomes a commonly used and short-term measure. Unlike the original Hotelling model, our model only has one stage where ports set prices. At this stage, we are trying to solve for the perfect Nash equilibrium (in our paper, the perfect Nash equilibrium refers to the optimal price set by each port) where locations are chosen already. Before the results of the Nash equilibrium are obtained, we must ascertain the profit function of the port, hence we start by deducing the demand function of each port. Suppose each consumer will buy a unit of service provided by the port and is indifferent to the choice of buying from the left one or the right one. The utility of the consumer choosing port 1 is equal to the utility of choosing port 2, and can be written as $u_\omega(a_1,p_1) = u_\omega(a_2,p_2)$. The formula can be expressed as follows: $k+\theta S_1 - t[(x_{1,2}-a_1)^2 + y_{1,2}^2] - p_1 = k + \theta S_2 - t[(a_2 - x_{1,2})^2 + y_{1,2}^2] - p_2$.

The value of the horizontal axis of the consumer $\omega(x_{1,2}, y_{1,2})$ would then be:

$$x_{1,2} = \frac{a_1+a_2}{2} + \frac{p_2 - p_1}{2t(a_2-a_1)} - \frac{\theta(S_2 - S_1)}{2t(a_2-a_1)} \tag{1}$$

The value of the vertical axis is $y_{1,2} \in [0,1]$.

Similarly, the boundary point between two adjacent ports except the n^{th} port is:

$$x_{i,i+1} = \frac{a_i + a_{i+1}}{2} + \frac{p_{i+1} - p_i}{2t(a_{i+1} - a_i)} - \frac{\theta(S_{i+1} - S_i)}{2t(a_{i+1}-a_i)} \tag{2}$$

Using the derived linear eqs. (1) and (2), the demand function of port 1 is denoted as follows:

$$D_1 = \int_0^1 \int_0^{x_{1,2}} dxdy = \frac{a_1+a_2}{2} + \frac{p_2-p_1}{2t(a_2-a_1)} - \frac{\theta(S_2-S_1)}{2t(a_2-a_1)} \tag{3}$$

The demand function of the i^{th} $(2 \le i < n)$ port is:

$$D_i = \int_0^1 \int_{x_{i-1,i}}^{x_{i,i+1}} dxdy = \frac{a_{i+1}-a_{i-1}}{2} + \frac{p_{i+1}-p_i}{2t(a_{i+1}-a_i)} - \frac{p_i - p_{i-1}}{2t(a_i - a_{i-1})} - \frac{\theta(S_{i+1}-S_i)}{2t(a_{i+1}-a_i)} + \frac{\theta(S_i - S_{i-1})}{2t(a_i - a_{i-1})} \tag{4}$$

The demand function of the n^{th} port is:

$$D_n = \int_0^1 \int_{x_{n-1,n}}^1 dxdy = 1 - \frac{a_{n-1}+a_n}{2} - \frac{p_n - p_{n-1}}{2t(a_n - a_{n-1})} + \frac{\theta(S_n - S_{n-1})}{2t(a_n - a_{n-1})} \tag{5}$$

Proposition 1: The demand function D_i is concave with respect to the price of port *i*.

Proof of proposition 1:

$$\frac{\partial D_1}{\partial p_1}=-\frac{p_1}{2t(a_2-a_1)},\ \frac{\partial D_i}{\partial p_i}=-\frac{p_i}{2t(a_{i+1}-a_i)}-\frac{p_i}{2t(a_i-a_{i-1})},\ \frac{\partial D_n}{\partial p_n}=-\frac{p_n}{2t(a_n-a_{n-1})}$$

As $0 \le a_1 \le a_2 \le a_i \le ... \le a_n \le 1$, $t > 0$, apparently, $\frac{\partial D_i}{\partial p_i}<0$.

From the above proposition, we could draw the conclusion that the ports have a motivation to decrease their prices to capture more freight source to improve their rankings, since the ranking standard is identified by ports' throughput internationally. However, huge throughput should not be equated with successful operation and efficiency. Ports just like other enterprises aim to extract maximum profit. Hence, ports should set prices in view of profits.

We suppose the service cost function is $f_i(S_i)$. According to the above formulations, we can obtain the profit functions as follows:

$$\Pi_i = p_i D_i - f_i(S_i) \tag{6}$$

We first consider the situation that the ports compete with each other and go a step further and obtain:

$$\Pi_1 = p_1[\frac{a_1+a_2}{2}+\frac{(p_2-p_1)-\theta(S_2-S_1)}{2t(a_2-a_1)}]-f_1(S_1) \tag{7}$$

$$\Pi_i = p_i[\frac{a_{i+1}-a_{i-1}}{2}+\frac{p_{i+1}-p_i}{2t(a_{i+1}-a_i)}-\frac{p_i-p_{i-1}}{2t(a_i-a_{i-1})}-\frac{\theta(S_{i+1}-S_i)}{2t(a_{i+1}-a_i)}+\frac{\theta(S_i-S_{i-1})}{2t(a_i-a_{i-1})}]-f_2(S_2),\ (2 \le i < n) \tag{8}$$

$$\Pi_n = p_n[1-\frac{a_{n-1}+a_n}{2}-\frac{(p_n-p_{n-1})-\theta(S_n-S_{n-1})}{2t(a_n-a_{n-1})}]-f_3(S_3) \tag{9}$$

Suppose that each port is a rational competitor and wants to maximize its profits. In this paper, we only discuss the problem with $\Pi_i > 0$.

Proposition 2: $\Pi_i > 0$ is concave with respect to price and has maximum values.

Proof of proposition 2:

The second order conditions $\frac{\partial^2 \prod_1}{\partial p_1^2}=-\frac{1}{t(a_2-a_1)}<0$ and $\frac{\partial^2 \prod_i}{\partial p_i^2}=-\frac{1}{t(a_{i+1}-a_i)}-\frac{1}{t(a_i-a_{i-1})}<0$ ($2 \le i < n$). This means that profit functions are concave with respect to price and have maximum values.

In order to solve the optimal results conveniently, we define the new compound variables: $m_{i,i+1}=a_i+a_{i+1}$, $d_{i+1,i}=a_{i+1}-a_i$, $s_{i+1,i}=S_{i+1}-S_i$, $p^*=(p_1,p_2,\cdots p_i \cdots p_n)^T$.

We maximize the profit functions, that is $\max_{p_i}\Pi_i, \forall i \in n$. Taking $\frac{\partial \Pi_i}{\partial p_i}=0$ we get the linear equation set as follows:

$$\begin{cases} -2p_1+p_2+tm_{12}d_{21}-\theta s_{21}=0 \\ \cdots \\ d_{i+1,i}p_{i-1}-2(d_{i,i-1}+d_{i+1,i})p_i+d_{i,i-1}p_{i+1}+td_{i,i-1}d_{i+1,i}(d_{i,i-1}+d_{i+1,i})-\theta(s_{i+1,i}d_{i,i-1}-s_{i,i-1}d_{i+1,i})=0 \\ p_{n-1}-2p_n-td_{n,n-1}m_{n,n-1}+2td_{n,n-1}+\theta s_{n,n-1}=0 \end{cases} \tag{10}$$

In order to attain a concise formula, we define two new matrices respectively:

$$A=\begin{bmatrix} -2 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ d_{32} & -2(d_{21}+d_{32}) & d_{21} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & d_{43} & -2(d_{32}+d_{43}) & d_{32} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & d_{54} & -2(d_{43}+d_{54}) & d_{43} & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & d_{i+1,i} & -2(d_{i,i-1}+d_{i+1,i}) & d_{i,i-1} & 0 & 0 \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & -2 \end{bmatrix} \tag{11}$$

$$b=\begin{pmatrix} tm_{12}d_{21}-\theta s_{21} \\ \cdots \\ td_{i,i-1}d_{i+1,i}(d_{i-1,i}+d_{i+1,i})-\theta(\mathrm{s}_{i+1,i}\,d_{i,i-1}-s_{i,i-1}d_{i+1,i}) \\ \cdots \\ -td_{n,n-1}m_{n,n-1}+2td_{n,n-1}+\theta s_{n,n-1} \end{pmatrix} \tag{12}$$

So the eq. (10) can be rewritten as:

$$Ap^{*}+b=0 \tag{13}$$

Decision variable p^{*} can be expressed as: $p^{*}=-A^{-1}b$

$$p^{*}=-\begin{bmatrix} -2 & 1 & 0 & \cdots & 0 & 0 \\ d_{32} & -2(d_{21}+d_{32}) & d_{21} & \cdots & 0 & 0 \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ 0 & 0 & d_{i+1,i} & -2(d_{i,i-1}+d_{i+1,i}) & d_{i,i-1} & 0 \\ 0 & 0 & 0 & 0 & 1 & -2 \end{bmatrix}^{-1} b \tag{14}$$

We can therefore draw the conclusion that the equilibrium price of each port is associated with the locations and service levels of ports and the inland freight rate. The more ports in the same region, the more parameters influence the prices of the ports. Thus, it is more difficult for us to decide the optimal prices of ports.

4. SIMULATION

4.1 Price simulation of three competitive ports

Without generality, we take three ports as an example to compare their prices. According to the results above, we obtain,

$$p_1^{*}=\frac{td_{21}[d_{32}(d_{31}+2)+3m_{12}d_{31}]+\theta d_{32}s_{21}-\theta d_{21}s_{32}-3\theta d_{31}s_{21}}{6d_{31}} \tag{15}$$

$$p_2^{*}=\frac{td_{21}d_{32}(d_{31}+2)+\theta d_{32}s_{21}-\theta d_{21}s_{32}}{3d_{31}} \tag{16}$$

$$p_3^{*}=\frac{td_{32}[d_{21}(d_{31}+2)-3m_{12}d_{31}+6d_{31}]+\theta d_{32}s_{21}-\theta d_{21}s_{32}+3\theta d_{31}s_{32}}{6d_{31}} \tag{17}$$

And we find that the following formulas are established.

$\frac{\partial p_1^*}{\partial S_1}=\frac{\theta(3d_{31}-d_{32})}{6d_{31}}>0$, $\frac{\partial p_2^*}{\partial S_2}=\frac{\theta}{3}>0$, $\frac{\partial p_3^*}{\partial S_3}=\frac{\theta(3d_{31}-d_{21})}{6d_{31}}>0$, $\frac{\partial p_1^*}{\partial S_2}=-\frac{\theta}{3}<0$, $\frac{\partial p_1^*}{\partial S_3}=-\frac{\theta d_{21}}{6d_{31}}<0$,

$\frac{\partial p_2^*}{\partial S_1}=-\frac{\theta d_{32}}{3d_{31}}<0$, $\frac{\partial p_2^*}{\partial S_3}=-\frac{\theta d_{21}}{3d_{31}}<0$, $\frac{\partial p_3^*}{\partial S_1}=-\frac{\theta d_{32}}{6d_{31}}<0$ and $\frac{\partial p_3^*}{\partial S_3}=-\frac{\theta}{3}<0$

So, the price increases with enhancements to its own service level and decreases with the increasing service levels of others. Since the ports' locations are fixed, the prices will change in terms of service levels. We will compare the optimal prices of three ports.

Suppose the service levels of three ports are the same, we obtain:

$$p_1^* = \frac{td_{21}[d_{32}(d_{31}+2)+3m_{12}d_{31}]}{6d_{31}} \tag{18}$$

$$p_2^* = \frac{td_{21}d_{32}(d_{31}+2)}{3d_{31}} \tag{19}$$

$$p_3^* = \frac{td_{32}[d_{21}(d_{31}+2)-3m_{12}d_{31}+6d_{31}]}{6d_{31}} \tag{20}$$

Proposition 3: The price of the port located in the middle is lower than one of the other two ports, that is $p_1^* > p_2^*$ or $p_3^* > p_2^*$.

Proof of proposition 3: According to the equilibrium prices above, we obtain:

$$p_1^* - p_2^* = \frac{td_{21}[-d_{32}(d_{31}+2)+3m_{12}d_{31}]}{6d_{31}} \tag{21}$$

$$p_3^* - p_2^* = \frac{td_{32}[-d_{21}(d_{31}+2)-3m_{12}d_{31}+6d_{31}]}{6d_{31}} \tag{22}$$

If $p_1^* > p_2^*$, then

$$3m_{12}d_{31} - d_{32}(d_{31}+2) > 0 \tag{23}$$

If $p_3^* > p_2^*$, then

$$6d_{31} - 3m_{12}d_{31} - d_{21}(d_{31}+2) > 0 \tag{24}$$

If the above two inequalities are not substantiated, that is $p_1^* < p_2^*$ or $p_3^* < p_2^*$, then

$$3m_{12}d_{31} - d_{32}(d_{31}+2) \le 0 \tag{25}$$

$$6d_{31} - 3m_{12}d_{31} - d_{21}(d_{31}+2) \le 0 \tag{26}$$

With inequality (25)+(26) we yield $6d_{31} - d_{31}(d_{31}+2) \le 0$. Further we get $d_{31}(4-d_{31}) \le 0$, which will mean:

$$d_{31} \ge 4 \tag{27}$$

Since $0 < d_{31} \le 1$, inequality (27) is unsubstantiated, and the above proposition is substantiated, namely $p_1^* > p_2^*$ or $p_3^* > p_2^*$.

In fact, the middle port competes to not only with the left rival but also the right rival, and hence has to decrease price to attract more freight source.

When the service levels of three ports are not the same, we yield,

$$p_1^* = \frac{td_{21}[d_{32}(d_{31}+2)+3m_{12}d_{31}]+\theta d_{32}S_{21}-\theta d_{21}S_{32}-3\theta d_{31}S_{21}}{6d_{31}} \tag{28}$$

$$p_2^* = \frac{td_{21}d_{32}(d_{31}+2)+\theta d_{32}S_{21}-\theta d_{21}S_{32}}{3d_{31}} \tag{29}$$

$$p_3^* = \frac{td_{32}[d_{21}(d_{31}+2)-3m_{12}d_{31}+6d_{31}]+\theta d_{32}S_{21}-\theta d_{21}S_{32}+3\theta d_{31}S_{32}}{6d_{31}} \tag{30}$$

We find out that the prices of ports are associated with the locations, service levels and inland freight rate, the relations of p_1^*, p_2^*, p_3^* are difficult to compare, however the optimal prices are all associated with S_{21} and S_{32}.

Suppose $a_1 = 0.2$, $a_1 = 0.4$, $a_1 = 0.6$, $t = 1$, $\theta = 1$. Figs. 2 to 4 show the changes of prices with respect to service levels, with the x-axis representing S_{21}, y-axis representing S_{32}, and z-axis representing p_i^*.

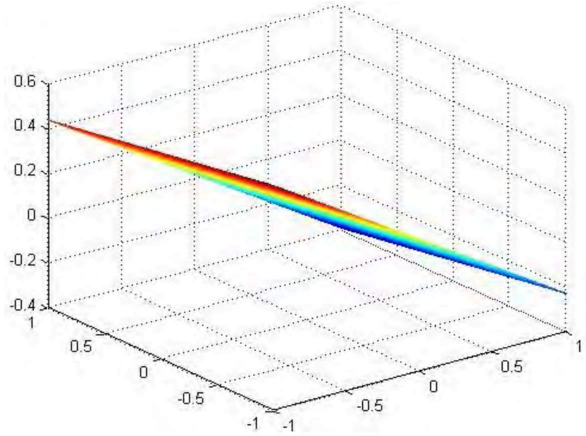

Figure 2: The change of p_1^* with respect to S_{21} and S_{32}.

Fig. 2 demonstrates that, as S_{21} and S_{32} reduce, p_1^* increases and S_{21} influences it more importantly than S_{32}.

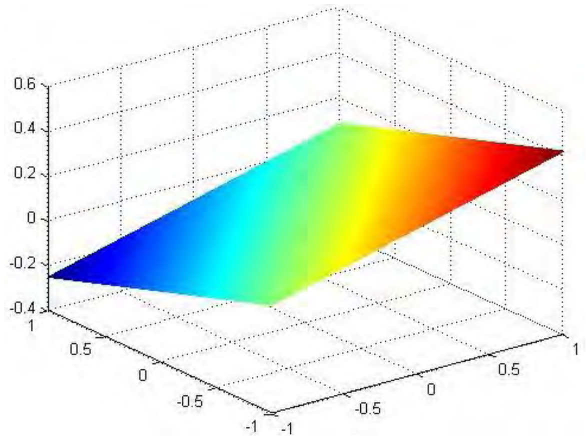

Figure 3: The change of p_2^* with respect to S_{21} and S_{32}.

Fig. 3 demonstrates that, as S_{21} increases, p_2^* increases and as S_{32} increases, p_2^* reduces. S_{21} and S_{32} have equal importance to it.

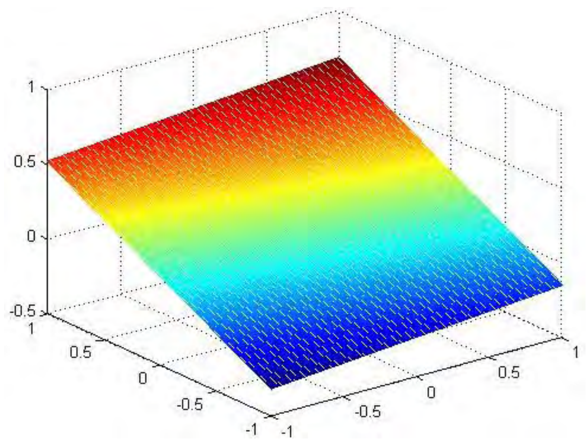

Figure 4: The change of p_3^* with respect to S_{21} and S_{32}.

Fig. 4 demonstrates that, as S_{21} and S_{32} increases, p_3^* increases and S_{32} influences it more importantly than S_{21}.

Figs. 2 to 4 only demonstrate the changes of p_i^* given the particular location settings of the ports. In fact, p_i^* should be positive meaningfully.

When the services levels are different, it is difficult to compare their prices in theory. We can find that most ports may levy higher prices when their service levels are higher.

4.2 Price and demand simulations of two different scenario settings: competition and cooperation

The original Hotelling model does not take cooperative factors into account. However, in our paper, we consider not only competition but also cooperation issues. In order to compare which strategy is better for ports easily and without generality, we also take three ports as an example. The equilibrium prices are under competitive conditions as discussed in the previous section. Next we consider the cooperation strategy applied by the ports. Suppose two ports cooperate together to form an alliance to compete with the other port. There are two forms of alliance; one is between next-door neighbours, while another occurs between geographically separated ports. In our paper, we only discuss the latter case. We design a cooperation scenario, where port 1 and port 3 cooperate with each other, and sign an agreement to set similar prices, provide the same service levels and share the market with each other. Consumers prefer the nearer port and are not willing to pay for the extra freight charge for longer distance if they choose the further port. These two ports as an alliance both compete with port 2. See Fig. 5.

The boundary points $x_{12}^{'}$ between port 1 and port 2 and $x_{23}^{'}$ between port 2 and port 3 are deduced on the basis of eqs. (2) and (4). Two co-operators maximize their common profits, with the sum of their demand and profits expressed respectively as follows,

$$D_{13}^{'} = 1 - \frac{d_{31}}{2} + \frac{d_{31}(p_2^{'} - p_1^{'})}{2td_{21}d_{32}} + \frac{\theta(d_{21}s_{32} - d_{32}s_{21})}{2td_{21}d_{32}} \tag{31}$$

Here $p_i^{'}$ represents the new price set by each port 1 and port 3, $D^{'}$ represents the demand function and $\Pi^{'}$ is the profit function after cooperation.

$$\Pi_{13}^{'} = p_1^{'}D_1^{'} + p_3^{'}D_3^{'} - f(S_1) - f(S_3) \tag{32}$$

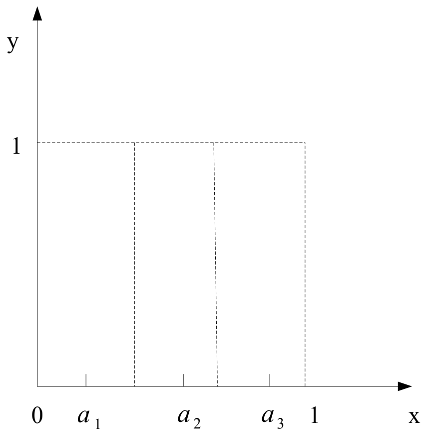

Figure 5: Cooperation between disjoined ports.

As $p_1^{'} = p_3^{'}$, we can also easily rewrite eq. (32):

$$\Pi_{13}^{'} = p_1^{'}[\frac{2 - d_{31}}{2} + \frac{d_{31}(p_2^{'} - p_1^{'})}{2td_{21}d_{32}} + \frac{\theta(d_{21}s_{32} - d_{32}s_{21})}{2td_{21}d_{32}}] - f_1(\mathrm{s}_1) - f_3(\mathrm{s}_3) \tag{33}$$

Then we obtain the profit of port 2 when port 1 and port 3 cooperate with each other as follows,

$$\Pi_2^{'} = p_2^{'}[\frac{d_{31}}{2} - \frac{d_{31}(p_2^{'} - p_1^{'})}{2td_{21}d_{32}} - \frac{\theta(d_{21}s_{32} - d_{32}s_{21})}{2td_{21}d_{32}}] - f(s_2) \tag{34}$$

Proposition 4: $\prod_{13}^{'}$ and $\prod_{2}^{'}$ is concave with respect to price and have maximum values.

Proof of proposition 4: The second order derivations $\frac{\partial^2 \prod_{13}^{'}}{\partial p_1^{'2}} < 0$ and $\frac{\partial^2 \prod_{2}^{'}}{\partial p_2^{'2}} < 0$ $(2 \le i \le n)$. This means that profit functions are concave with respect to price and have maximum values.

So taking $\frac{\partial \prod_2^{'}}{\partial p_2^{'}} = 0$ and $\frac{\partial \prod_{13}^{'}}{\partial p_1^{'}} = 0$, then we get the solutions:

$$p_1^{'*} = \frac{t(4-d_{31})d_{21}d_{32} + \theta(d_{21}s_{32} - d_{32}s_{21})}{3d_{31}} \tag{35}$$

$$p_2^{'*} = \frac{t(2+d_{31})d_{21}d_{32} - \theta(d_{21}s_{32} - d_{32}s_{21})}{3d_{31}} \tag{36}$$

Substitute the two solutions (35) and (36) into eqs. (31) and (33), and we get the maximum demand and profit of the alliance.

$$D_{13}^{'*} = \frac{t(4-d_{31})d_{21}d_{32} + \theta(d_{21}s_{32} - d_{32}s_{21})}{6td_{21}d_{32}} \tag{37}$$

$$\prod_{13}^{'*} = \frac{[t(4-d_{31})d_{21}d_{32} + \theta(d_{21}s_{32} - d_{32}s_{21})]^2}{18td_{21}d_{31}d_{32}} - f(s_1) - f(s_3) \tag{38}$$

Now we compare the change in demand under the conditions of competition and cooperation. We can rewrite the total demand of port 1 and port 3 when they are competitors.

$$D_{13}^{*} = 1 - \frac{d_{31}}{2} + \frac{p_2^{*} - p_1^{*} - \theta s_{21}}{2td_{21}} - \frac{p_3^{*} - p_2^{*} - \theta s_{32}}{2td_{32}} \tag{39}$$

A new parameter is defined as $\Delta D_{13} = D_{13}^{'*} - D_{13}^{*}$.

Proposition 5: Whether $s_{i+1,i}$ is positive or not, ΔD_{13} is always positive.

Proof of proposition 5: On the basis of eqs. (35), (36) and (39), we can easily calculate the difference value between D_{13}^{*} and $D_{13}^{'*}$ as:

$$\begin{aligned}\Delta D_{13} &= \frac{3td_{21}d_{31}^2d_{32} - \theta(d_{32}^2 + d_{21}d_{32} - d_{31}d_{32})s_{21} + \theta(d_{21}^2 + d_{21}d_{32} - d_{21}d_{31})s_{32}}{12td_{21}d_{31}d_{32}} \\ &= \frac{3td_{21}d_{31}^2d_{32} - \theta[d_{32}(d_{32} + d_{21}) - d_{31}d_{32}]s_{21} + \theta[d_{21}(d_{21} + d_{32}) - d_{21}d_{31}]s_{32}}{12td_{21}d_{31}d_{32}}\end{aligned} \tag{40}$$

As $d_{32} + d_{21} = d_{31}$, ΔD_{13} is equal to $d_{31}/4$ which is always positive.

A very important conclusion can be drawn from the above result. When port 1 and port 3 cooperate with each other with an agreement on price strategy, the total sums of their market demand are higher than that if they were to compete with each other. Therefore, they have a motivation to form an alliance to capture more market share from port 2.

Next, we compare the change in profit under the conditions of competition and cooperation. We define a new parameter as follows,

$$\Delta \prod_{13} = \prod_{13}^{'*} - \prod_1^{*} - \prod_3^{*} \tag{41}$$

$\Pi_{13}^{'*}$ is the total profit of port 1 and port 3 when they are cooperative. Π_1^* and Π_3^* represent the profits of port 1 and port 3 respectively when they are competitors. Then, we get:

$$\Delta\Pi_{13} = \frac{t(4-d_{31})^2 d_{21} d_{32}}{18 d_{31}} - \frac{t d_{21}[d_{32}(d_{31}+2)+3m_{12}d_{31}]^2}{72 d_{31}^2} - \frac{t d_{32}[d_{21}(d_{31}+2)+3d_{31}(2+m_{12}-2m_{23})]}{72 d_{31}^2} - F(s_{31}) - F(s_{32}) - F(s_{21}) \quad (42)$$

$F(s_{31})$, $F(s_{32})$ and $F(s_{21})$ are compound functions related to s_{31}, s_{32}, s_{21} respectively. It is difficult to estimate whether $\Delta\Pi_{13}$ is positive or not. This illustrates that $\Delta\Pi_{13}$ is related to the locations and service levels of the three ports. Since the locations of the ports are fixed, the service levels will be the key factor affecting profit.

5. DISCUSSION AND CONCLUSION

China's economy has been seen rapid development in domestic and foreign trade and has become one of the largest markets for water transportation with a growth rate averaging 12.44 % over the last three years. Numerous Chinese ports are attempting to attract greater throughputs with various measures such as increasing investment, improving efficiency of service and introducing new technologies. China's port industry has presented a pattern consistent with market competition. After the financial crisis, global trade is on the rise again. Many ports are planning to employ a new strategy for pricing and service to respond to the growth in maritime trade and the needs of hinterland economic development.

This paper examines the changes in the market shares and profits of ports based on a game model. Unlike previous work considering only two rival ports, here multiple ports in the same region are involved using a Hotelling model. Two types of scenarios are set up, one involving competition, and the other involving cooperation. Under competition conditions, the equilibrium prices of multiple ports are deduced. Then three ports are taken as an example to simulate the optimal prices. By discussing the optimal pricing strategy of multiple ports serving the same hinterland, we find out that the pricing strategy of multiple ports is a complex decision-making process which is influenced by many factors. Theory studies indicate that if service levels of three ports are the same, the optimal price of the port located at the middle of them is lower and, if not, the optimal prices related to locations and service levels are compared with difficulty.

Under cooperation conditions, two disconnected ports are assumed to be an alliance with the same price and the equilibrium prices and optimal market shares and profits are then deduced. When these two ports cooperate with each other with an agreement on price strategy, the total sums of their market demand are higher than if they were to compete with each other. Therefore, they have a motivation to form an alliance to capture a greater market share. As for changes in profits, this paper's conclusion is related to the locations and service levels of three ports. Since the locations of the ports are always fixed, the service levels will be the key factor affecting profit.

Our future work will study other forms of alliance between ports, such as those involving technology, service and investment. Different forms of alliance may lead to different changes in market share and profits of ports. We will compare competition strategy with cooperation strategy under different alliance scenarios and the results will provide some theoretical advice to port enterprises.

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